Homogeneous EM Calorimeter R&D for EIC

(part of eRD1)

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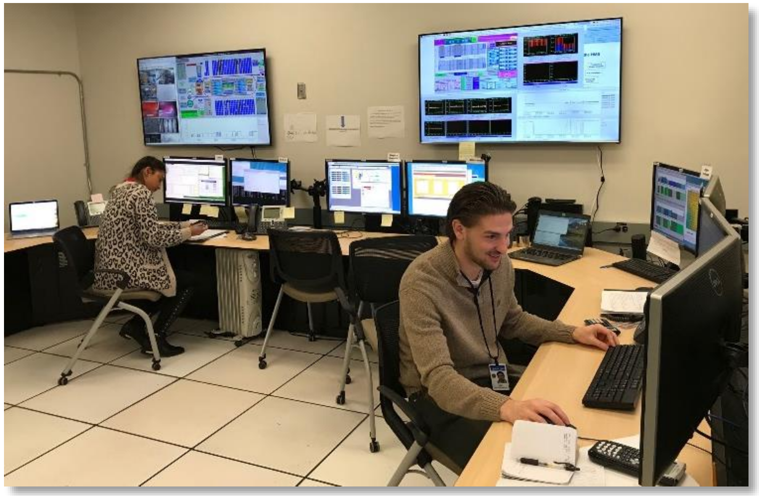
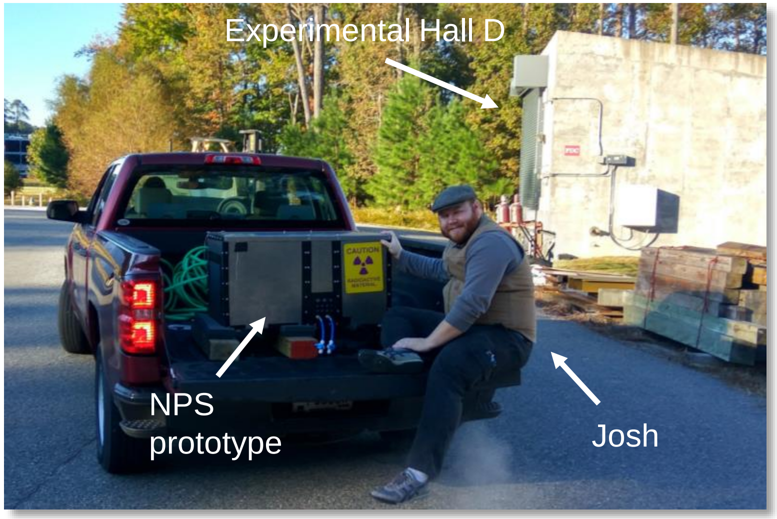
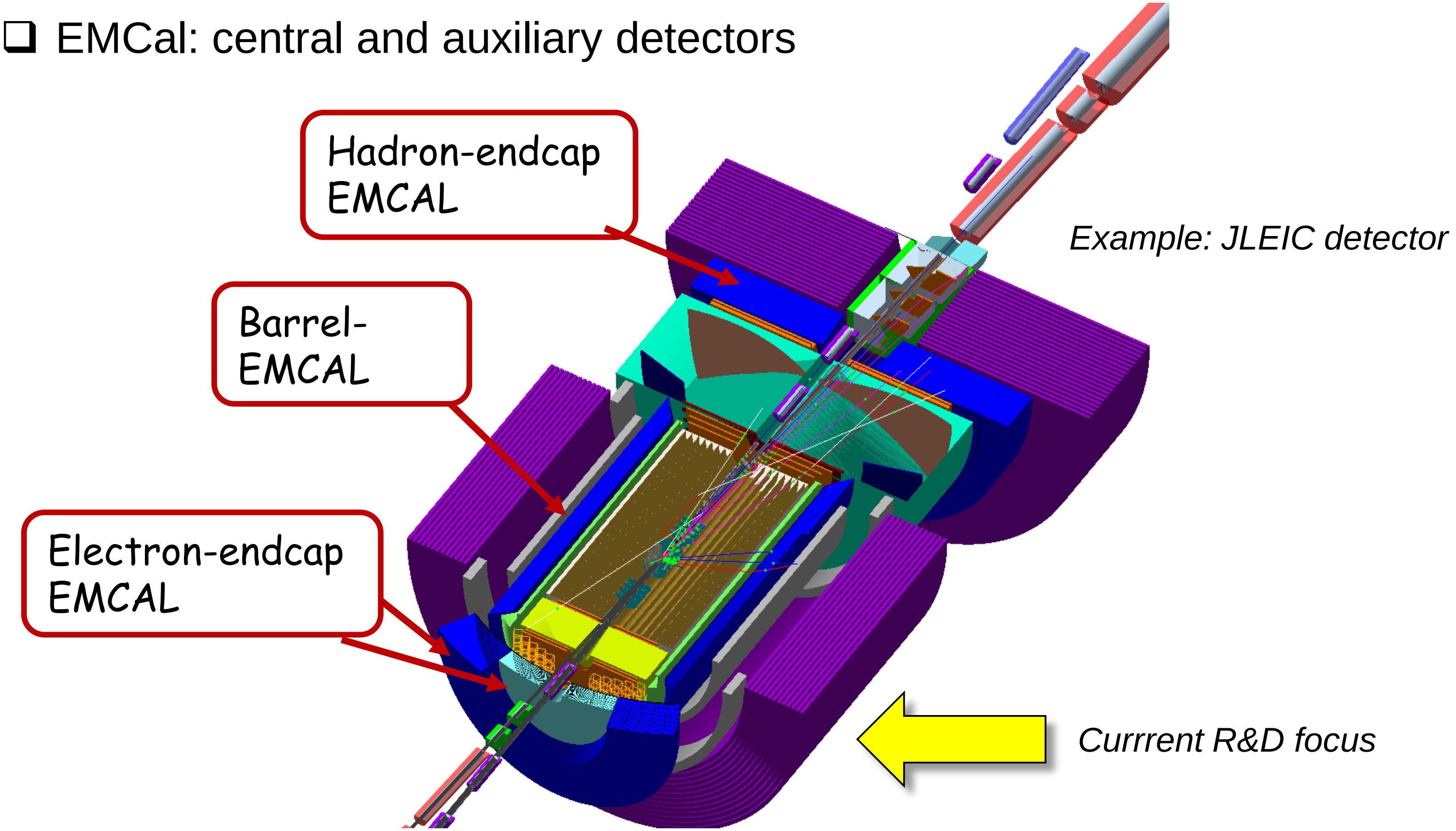




Homogeneous EM Calorimetry

- EMCal: central and auxiliary detectors



- Materials:
  - **Lead Tungstate ($PbWO_4$) –** high resolution, \$15-25/cm^3, limited vendors
  - **Glass (DSB:Ce) –** alternative active material, easier to manufacture than crystals and more cost effective

What was planned for FY19

Work with vendors on cost-effective production of high-quality scintillator material

- Develop crystal and glass formulation and production processes, and optimization of quality assurance/quality control procedures
- Develop long-term goals and milestones for material development

Start beam test program with EMCal prototype – establish real resolutions

- Design and commission 3x3 and 12x12 prototypes including real readout system
- Analyze data from prototype beam test program

Start working on future activities – readout, matching materials, etc.

- Set up a test bench for testing different readout options
- Raw material control and purity, investigate new sources of raw material
- Start designing simulations for material matching in different regions

What was achieved in FY19 – to date

With commitment of internal university and laboratory funds and through synergy with the NPS project at JLab we made progress even within constrained FY19 budgets

Progress

Work with vendors on cost-effective production of high-quality scintillator material

- **Characterized 560 SICCAS and 211 CRYTUR $PbWO_4$ crystals, feedback to vendors**
- **Produced & characterized 40 glass samples; formulation optimized, initial scale-up**
- **Established QA procedures with vendors and investigated raw material options**
- **Submitted orders for 500 additional SICCAS and 500 CRYTUR crystals**

Progress

Start beam test program with EMCal prototype – establish real resolutions

- **Designed and commissioned 3x3 and 12 x 12 arrays with test beam**
- **Preliminary data analysis completed – optimizations ongoing**

Progress

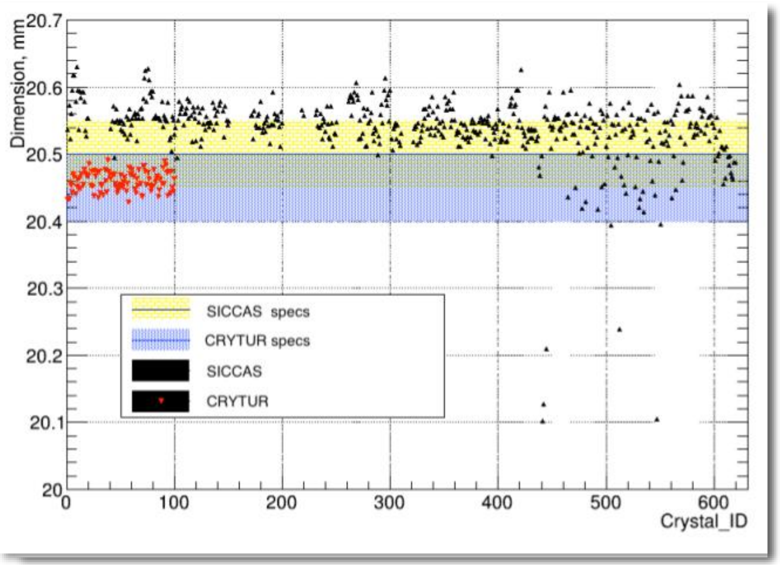
Start working on future activities – readout, matching materials, etc.

- **Commissioned a test bench for testing different readout options**
- **Evaluated MC simulations for homogeneous calorimetry in additional regions**

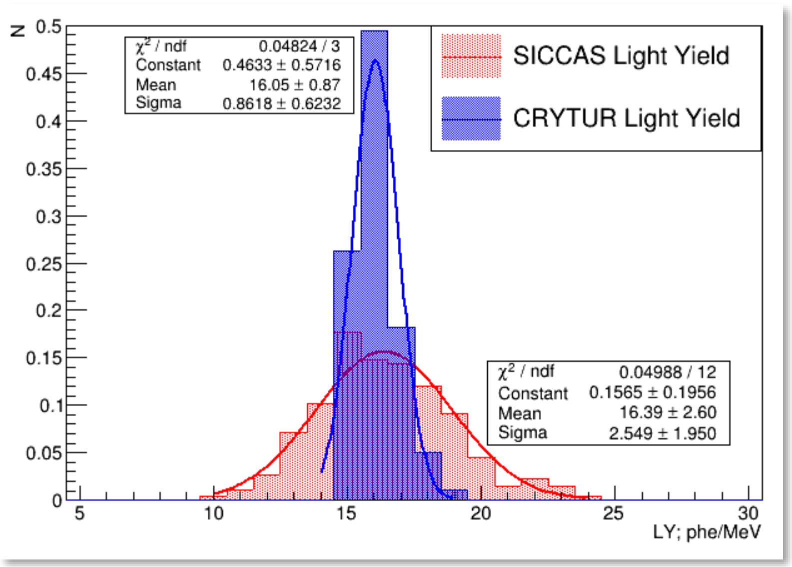
Crystal Activities – characterization and vendors

- **SICCAS**: failure rate ~35% for crystals received 2017-19 due to major mechanical defects – an additional 15% are questionable
  - Meetings in spring 2019 to establish quality control procedures
- **CRYTUR**: Strict quality control procedures – so far 100% of crystals accepted
  - Meetings in summer 2019 to improve capacity and discuss raw material availability

Quality analysis:



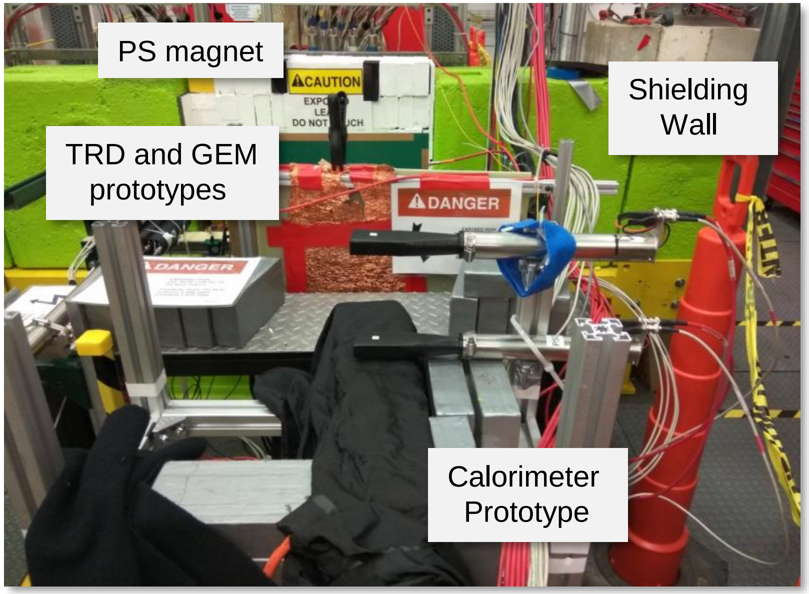
Dimensions



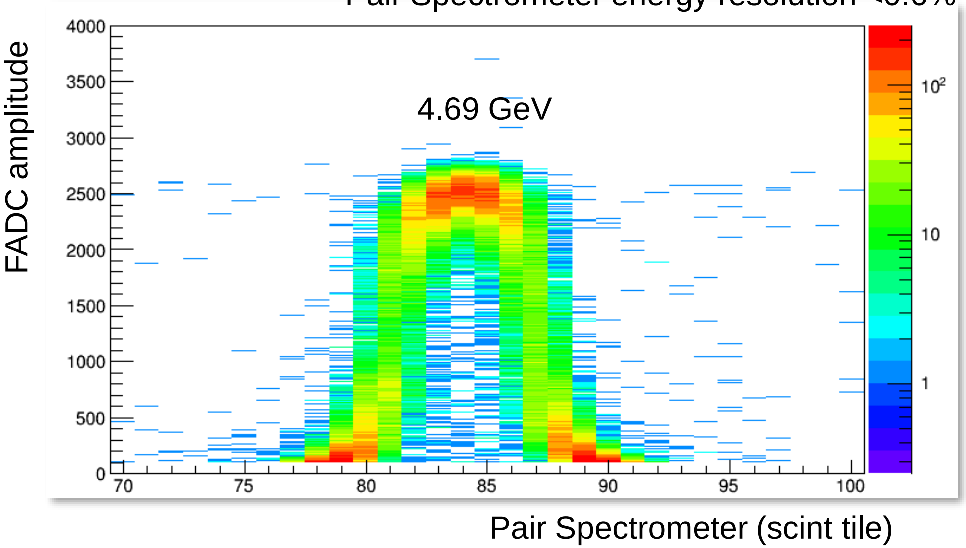
Light yield

Crystal Activities – Beam Test Program

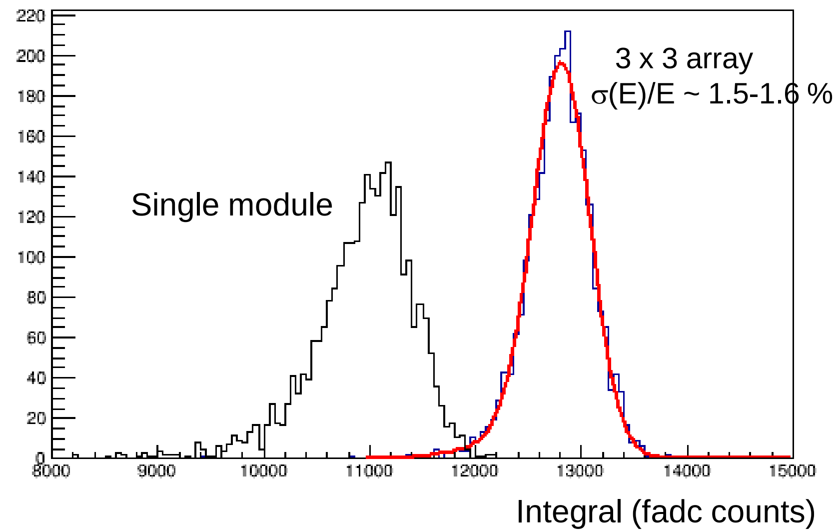
- Commissioned a 3x3 prototype of geometry representative of NPS and EIC EMCal
- Beam energy provided by pair spectrometer - select electrons going through the center of the middle crystal
- Allows for quick configuration tests, estimation of energy resolution, and comparison of crystal properties



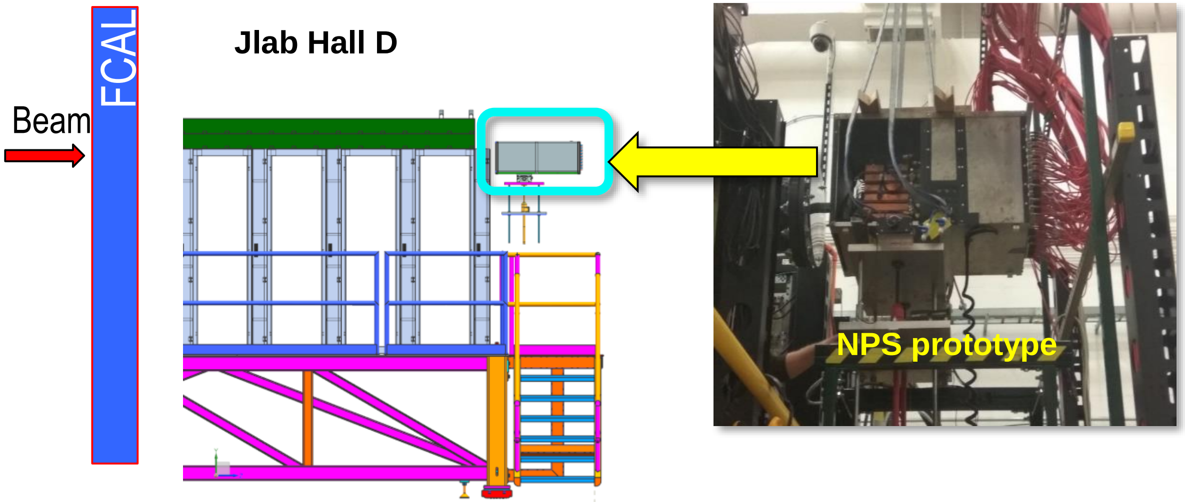
Pair Spectrometer energy resolution <0.6%



Max. rate/crystal ~250kHz at ~30MeV threshold*



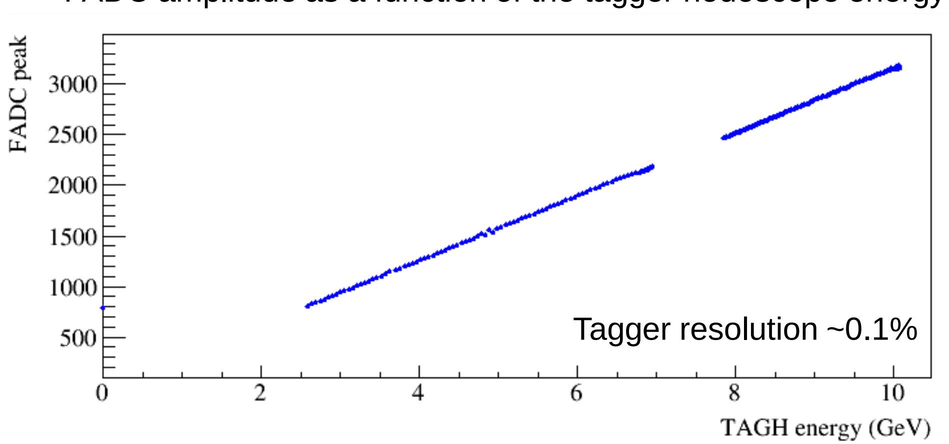
Crystal Activities – Beam Test Program

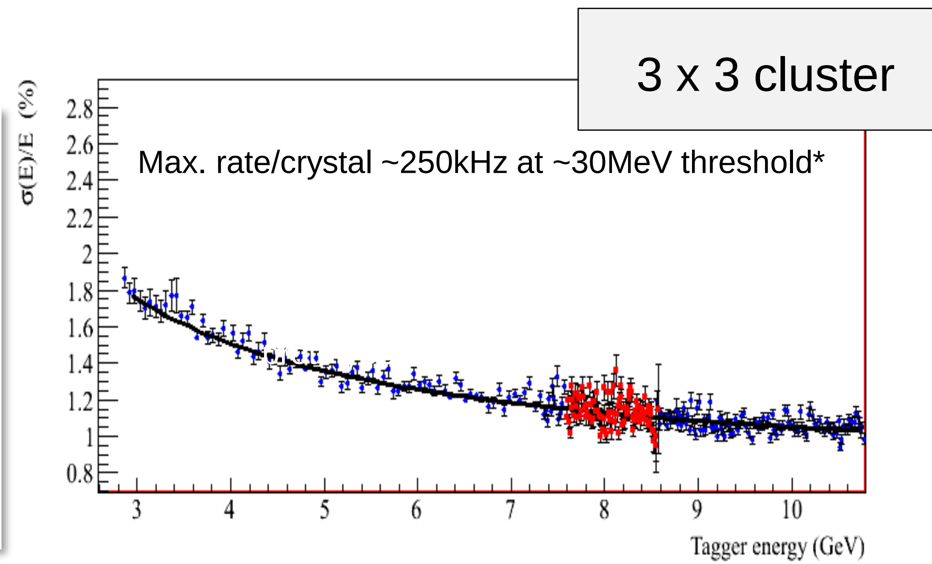


- ❑ Commissioned a 12 x 12 prototype
- ❑ Beam energy provided by tagger hodoscope
- ❑ Allows for data over larger energy range and also study of linearity

❑ Preliminary energy resolution for 3x3 cluster: $\sigma(E)/E = 0.7 + 2.2/\sqrt{E} + 2.8/E$

FADC amplitude as a function of the tagger hodoscope energy





Test Lab for crystal and glass Readout

- ❑ Assembled three Multi-gap Resistive Plate Chambers to map out material response over large area in short time
  - ❖ Chamber dimensions: 80x160 cm
- ❑ Using streaming readout boards developed at INFN for EIC streaming readout
  - ❖ Time stamp from board allows to correlate hits with chambers
- ❑ Achieved ~100 ps time resolution for determining detector response
- ❑ Procuring a GPS system to be used in conjunction with the readout board to complete the setup

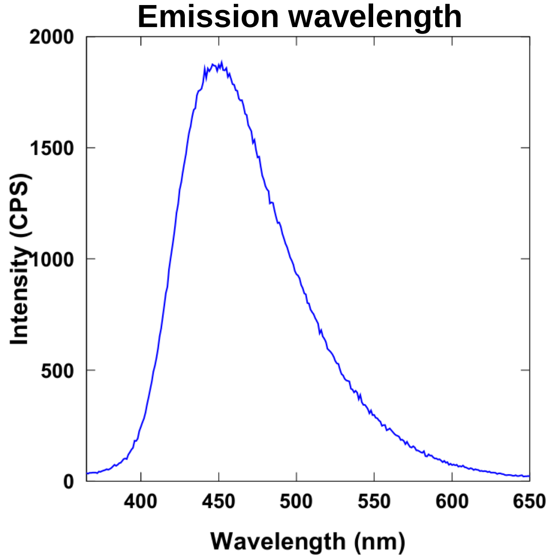

Setup at INFN-GE

Glass Scintillator – formulation optimization

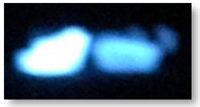
❑ Two glass formulations for calorimeter application

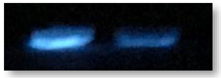
VSL-Scintilex-G4 (nominal)

VSL-Scintilex-T1



Scintillation light

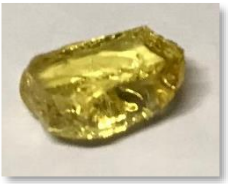




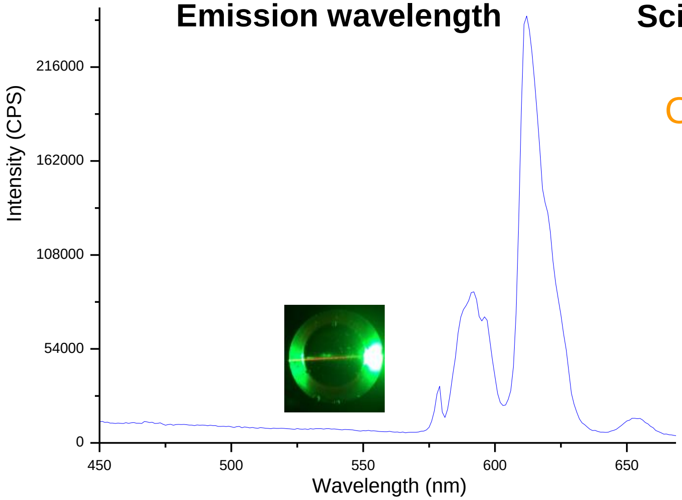
- ➢ Nominal: optimized LY, timing, radiation hardness, etc.
- ➢ Increased density compared to nominal, lower LY, but still higher than PWO

❑ Formulations with initial emission wavelength tuning

VSL-Scintilex-SC1



VSL-Scintilex-EC1



Scintillation light

Orange-red

- ➢ Very high-density compared to nominal, emits at >550nm, good LY
  - ○ Additional wavelength tuning ongoing

Glass Scintillator – Radiation Hardness

- ❑ High dose radiation tests – progress with new method at CUA/VSL/Scintilex

VSL-Scintilex-S1 **VSL-Scintilex-S2** **VSL-Scintilex-G4 (nominal)**



Before irradiation



After 2min 160KeV
Xray at >3k Gy/min


After curing

- ❑ T, SC, EC series are EM radiation hard with new method too
- ❑ Hadron irradiation test planned

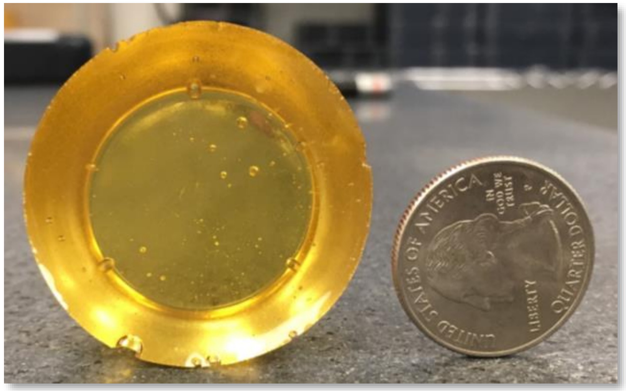
Glass Scintillator – Initial Scale-Up

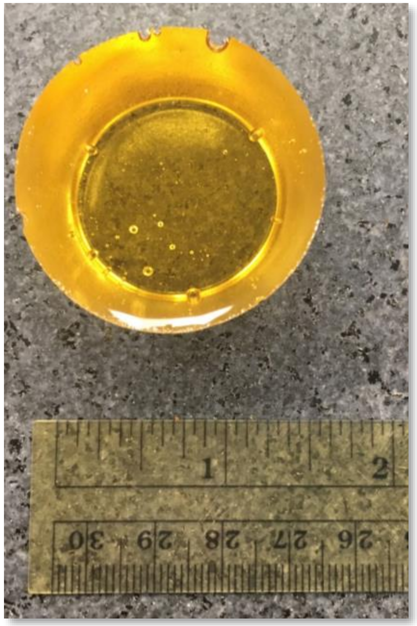
- ❑ Progress with scale-up – medium-size samples produced, issues preventing further scale-up identified, solutions are being implemented and tested

Example: SC1 glass

1cm x 1cm x 0.5cm (test size)

2cm x 2cm x 4cm (medium size, before cut/polish)





- ➢ Bubbles on surface only – will be removed during cutting and polishing

What was not achieved

- **Procurement of CRYTUR large-volume crystals** due to continued delays in commissioning of larger crucibles. **Production of larger glass blocks** due to intrinsic challenges of scale-up process. Progress on both expected soon.

- **Characterization of additional crystals and development of MC simulations** slowed down in part due to lack of dedicated (student) support – aim to have characterized ~700 CRYTUR and ~1000 SICCAS crystals by end of next period

- **Analysis of prototype data to study performance -** expected over next period, also important for optimizations and additional prototype run

- **Long-term goals and milestones** – anticipate an initial estimate over next period when additional information on crystal/glass production vendors, industry partnerships, and funding becomes available

Overview FY20 Plans

- **Continue working with vendors on crystal/glass production** – optimize QA procedures, material characterization to provide feedback; investigate alternative sources of raw material

- **Produce larger glass samples** with adequate surface quality for physical, luminescence, and radiation hardness tests

- **Prototype beam test program** – quantify performance and response of crystal and glass to different photosensors and streaming readout

- **Extend evaluation of homogeneous calorimetry – **develop MC for resolution studies and matching crystal/glass, increase efforts to other regions

- **Additional radiation hardness studies** – evaluate resistance to hadron radiation (MC40 synchrotron) and higher EM radiation doses (IPNO)

- **Submit SBIR/STTR proposal** – glass scintillator development

SCINTILEX

Budget - FY20 request by institution

Item	Full budget ($k)	20% cut ($k)	40% cut ($k)
CUA/VSL/Scintilex	**80**	**64**	**48**
Technical support for glass prototype	11	8.8	6.6
Student support - glass/crystal characterization and simulation	30	24	18
Equipment	5	4	3
Travel	5	4	3
Overhead	29	23.2	17.4
IPN-Orsay	**20**	**16**	**12**
Equipment	9	9	9
Materials	1	1	1
Travel	2	1.5	0
Student Support	5	2	0
Overhead	3	2.4	1.8
INFN-GE	**20**	**16**	**12**
Equipment (front-end electronic boards for light sensor readout, additional photo-sensors)	7	5.5	3
Materials (cables, mechanical supports…)	2	1.5	1
Travel	9	8	7
Overhead	2	1.5	1
TOTAL	**120**	**96**	**72**

Goals of the Consortium

Develop calorimeters that meet the requirements of physics measurements at an EIC – including all regions of the detector

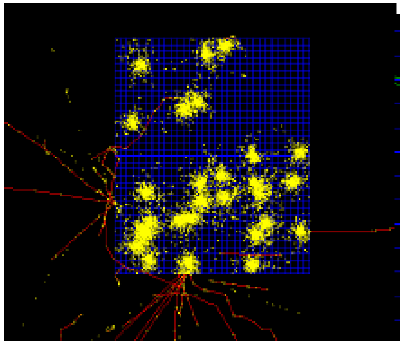
Systematic uncertainties are expected to be the main limiting factor in extracting the underlying physics

- ***Reduce systematic uncertainty*** on a broad range of physics measurements by employing ***different technologies***
- Broaden the spectrum to include ***new technologies*** that could potentially offer ***improved performance, lower cost, mitigate risk and broaden user involvement***

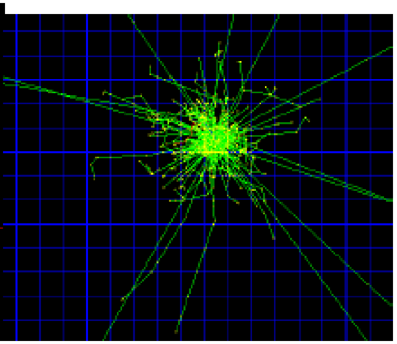
Regions and Physics Goals	Calorimeter Design
Lepton/backward: EM Cal ○ Resolution driven by need to determine (x, Q^2) kinematics from scattered electron measurement ○ Prefer 1.5%/√E + 0.5%	**Inner EM Cal for for $\eta < -2$:** ➢ Good resolution in angle to order 1 degree to distinguish between clusters ➢ Energy resolution to order (1.0-1.5 %/√E+0.5%) for measurements of the cluster energy ➢ Ability to withstand radiation down to at least 2-3 degree with respect to the beam line. **Outer EM Cal for $-2 < \eta < 1$:** ➢ Energy resolution to 7%/√E ➢ Compact readout without degrading energy resolution ➢ Readout segmentation depending on angle
Ion/forward: EM Cal ○ Resolution driven by deep exclusive measurement energy resolution with photon and neutral pion ○ Need to separate single-photon from two-photon events ○ Prefer 6-7%/√E and position resolution < 3 mm	
Barrel/mid: EM Cal ○ Photons and neutral pions from SIDIS and DES in range 1-10 GeV, so absolute energy uncertainty in photon should be 100 MeV ○ Leads to order 10%/√E	**Barrel, EM calorimetry** ➢ Compact design as space is limited ➢ Energy resolution of at least order 10%/√E, and likely better
Ion/Forward: Hadron Cal ○ Driven by need for x-resolution in high-x measurements ○ Need Δx resolution better than 0.05 ○ For diffractive with ~50 GeV hadron energy, this means 40%/√E	**Hadron endcap:** ➢ Hadron energy resolution to order 40%/√E, ➢ EM energy resolution to < (2%/√E + 1%) ➢ Jet energy resolution < (50%/√E + 3%)

Glass Scintillator – very preliminary simulations

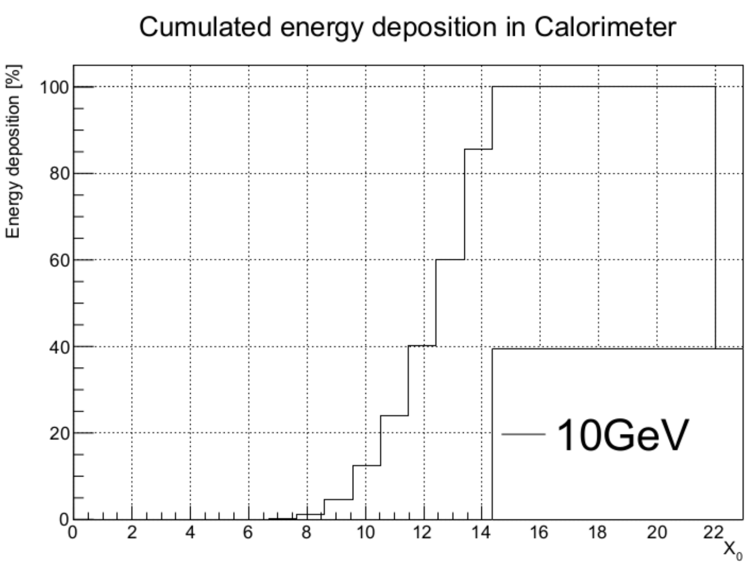
- Initial GEANT4 simulation of a detector array of 31x36 glass blocks
  - Glass block dimensions: 20.5 x 20.5 x 200 mm and wrapped in VM2000
  - Optical properties based on measurements, e.g. transmittance and light yield

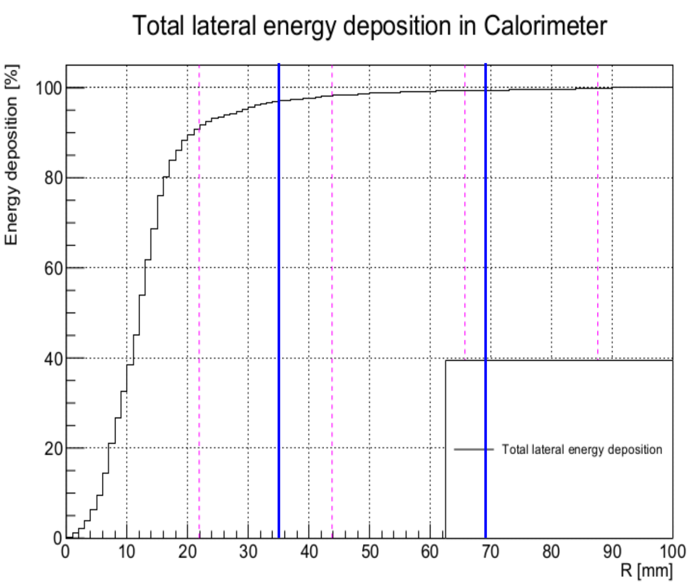


1 GeV photons distributed on the surface of the detector



1 GeV photon creating a shower





Moliere radius glass: 3.5 cm